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FLUTTER TESTS OF B-34 FIN-RUDDER-TAB SYSTEM

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

FLUTTER TESTS OF B-34 FIN-RUDDER-TAB SYSTEM

By Theodore Theodorsen and N. H. Smith

SUMMARY

Tests on the B-34 fin-rudder-tab assembly were performed in the NACA 8-foot high-speed tunnel. Two cases of tab flutter were studied. It was shown conclusively that the frequency of the original or heavy tab was too low and caused coupling with one of the lower bending frequencies. A general conclusion was made that the tab frequency should be considerably higher than the lower modes of the fin-rudder assembly because there is generally a weaker coupling between the tab and the higher mode responses.

PRELIMINARY VIBRATION TESTS

Rather extensive vibration tests were made on the vertical tail before it was placed in the test section of the NACA 8-foot high-speed tunnel. The tail surface was mounted on a horizontal stabilizer of constant cross section and having a span of $32\frac{3}{4}$ inches. This stabilizer was mounted rigidly on two 4-inch-angle iron brackets that were fastened to a large concrete block.

A number of rudder modes were studied. A General Electric moving coil shaker was attached to the lower-rudder trailing edge. Phases for various parts of the tail surface, which were obtained by use of a Western Electric pickup in conjunction with the pickup on the shaker, were compared on a cathode-ray oscillograph. The horizontal node for the torsion mode was found to lie about 3 inches below the bottom of the tab. The frequency was 41 cycles per second. The rudder paddles vibrated out of phase with respect to the adjacent parts of the rudder.

Vibration frequencies for both light and heavy tabs were also obtained. The rudder was restrained by wooden beams held firmly against the surface just ahead of the tab hinge line. The shaker was attached to the tab 1 inch from the tab hinge line by a rubber suction cup. The weight of the moving part of the shaker is 0.6 pound. This weight is negligible as it introduces an error of less than 1 percent in the frequency determination. The frequency of the heavy tab was found to be 32.5 cycles per second when the double amplitude of the lower trailing edge was greater than 1/4 inch. The frequency was less for smaller amplitudes because of the play in the tab linkage system. It should be noted that the rudder torsion frequency and the tab frequency are not the same as those found on the tail surface tested in vibration by K. Unholtz of Vega Aircraft Corporation.

When a shaker was attached to the top of the fin, a fin-rudder cantilever mode having a frequency of 11.3 cycles per second was excited. All parts of the rudder appeared to be in phase with the upper part of the fin.

A mode of vibration at a frequency near that of the heavy tab was excited when the shaker was attached to either the lower rudder or the lower fin. The tab rod was disconnected and the tab was connected to the rudder at the lower trailing edge of the tab during these tests. The response peak was broad and the maximum was found at various frequencies between 30 and 33 cycles per second. The average value of the frequency is given in table I, which includes all vibration-test frequencies. The question arose as to whether the mount had a natural frequency in the same range. After the wind-tunnel tests the tail surfaces last used in the tunnel were mounted on the concrete block in such a way as to lower the mount frequency to 10 cycles per second in horizontal vibration. This arrangement did not change the frequency of the tail response. The nodes and phases for this mode are shown in figure 1. Amplitudes were largest on the lower-fin tip and lower-rudder paddle and at the top of the trailing edge of the rudder near the top of the tab.

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WIND-TUNNEL TESTS

Installation and Instrumentation

Five midget accelerometers obtained from the Glenn L. Martin Co. and one tab and one rudder position indicator were mounted in the tail surface at locations as shown in figure 2. These pickups were used in conjunction with bridges, amplifiers, and an oscillograph obtained from the Consolidated Engineering Corp.

The vertical tail and horizontal stabilizer were mounted in the NACA 8-foot high-speed tunnel on four vertical steel leaf springs, which were attached rigidly to the tunnel and hinged on ball bearings at the ends of the horizontal stabilizer as indicated in figure 3. The springs were designed to give side motion simulating side bending of the fuselage. The frequency, however, was 7.3 cycles per second rather than the 8.3 cycles per second measured for the airplane.

Flutter Tests

Data from vibration tests at zero airspeed, which were made in the tunnel before each flutter test, are recorded in table I. A typical oscillograph record for rudder torsion is shown in figure 4. In all tests a heavy tab, having a moment of inertia of 0.102 inch-pound-second^2 about its own hinge line, was used.

Tests were made in the tunnel with the tail in the following conditions:

(1) Rudder trim-tab control unit as in airplane; tab play, 0.6° (normal play)

(2) Rudder trim-tab control unit as in airplane; tab play, 1.05°

(3) Spring substituted for rudder trim-tab control unit to lower tab frequency; tab play, 0.4° (minimum)

Because of an error in measuring tunnel velocity for the tests made under condition (1), the flutter was first encountered during a period of rather rapid increase in the speed of the tunnel, and the tab motion became excessive. The flutter caused damage to the rudder trailing edge at the tab push-rod cut-out and the skin of the upper rudder was buckled slightly in the vicinity of the rudder mast. This damage is shown in figure 5.

After the vibration tests, the run was repeated without repairs to the rudder surface. The tunnel velocity was increased gradually and oscillograph records were taken frequently. A plot of tab amplitude against tunnel velocity for the range between 260 and 315 miles per hour (tab play, 0.6°) is given in figure 6. A typical oscillograph record of the resulting mild tab flutter is shown in figure 7. The frequency and phases measured from a similar record are given in table II.

For condition (2), the amount of tab play was increased to 1.05° by machining one of the tab push-rod bearing bolts to a smaller diameter than standard. Tunnel velocities were again increased until a velocity of 354 miles per hour was reached without flutter. The oscillograph records show tab motion of small amplitude, however, at a frequency of 34 cycles per second. Amplitudes from these records are plotted in figure 6. A typical oscillograph record obtained from tests made under condition (2) is shown in figure 8. This test was discontinued because it was feared that the flutter would be severe, as the earlier tunnel velocity (for condition (1)) had been exceeded by a considerable amount.

For condition (3), the rudder trim-tab control mechanism was removed from the fin and a spring was substituted in order to study the effect of tab frequency. Vibration tests indicated that the tab frequency was reduced to 19 cycles per second. Severe flutter occurred at a velocity of 368 miles per hour and the upper tail surfaces failed, the tab being blown out completely. The flutter involved horizontal displacements of several inches at the tops of the mount springs, and the top of the fin moved about 1 foot from center as shown in figure 9 by the marks on the top of the tunnel. Figure 10 shows the damaged surfaces. The flutter was so sudden and so violent that the oscillograph records were not taken until after the surface had attained large amplitudes, and no trace could be found on the records for the tab position indicator, which evidently had broken in the meantime.

It was decided that if less severe flutter could not be produced with a spring giving low tab frequency little of the remaining part of the program could be carried out, since most of the program involved conditions that lowered the tab frequency.

A new upper fin without a de-icer was obtained from the Navy (designation PV-1 in table I) and the pickups were installed in a second upper rudder. The tab frequency was made as nearly the same as that of the previous case as possible. In order to provide a means for exciting the rudder, a small cable was run through and fastened to the upper-rudder trailing edge just above the tab. The cable ends were run through holes in the walls of the tunnel, passed over pulleys, and brought to an observation station below the tunnel.

Vibration tests were made previous to the run as before. From tachometer readings on the shaker and from oscillograph records showing the responses to a sharp blow on the fin, the tab frequencies were determined approximately as 18 cycles per second when the rudder was free and the tab amplitude small (oscillograph record) and 20 cycles per second when the rudder was blocked (shaker tachometer reading).

During the test in the tunnel one end of the steel cable was jerked at tunnel velocities of 275, 301, 311, and 321 miles per hour. The resulting oscillograph record taken at 311 miles per hour is reproduced in figure 11. At 321 miles per hour flutter was started by jerking one end of the cable, was damped by pulling on both ends of the cable, and became severe when the cable was released. Pulling the cable ends failed to restrain this large-amplitude flutter because one of the pulleys broke. An oscillograph record of the flutter at 321 miles per hour is given in figure 12. Data from this record are given in table III. When the tunnel was shut down, it was found that rivets in the horizontal stabilizer had been pulled, the fin had a list, and the tab was locked in right position.

The tests were discontinued as the time allotted to the experiment did not permit repair of the model.

FLUTTER MODES

Table II and the oscillograph record in figure 7 show the rudder paddles and the upper-rudder trailing edge to be essentially in phase with one another in the case of the mild flutter. These parts of the rudder are in phase in the vibration mode pictured in figure 1. Also, the tab frequency is very near the frequency for this mode. It is therefore concluded that the flutter mode consisted of a coupling between the tab and the mode of figure 1.

The severe flutter involved large-amplitude motion of the fin and the leaf springs. The coupled frequency of the upper fin vibrating out of phase with the leaf springs is believed to be about 14 cycles per second, since this frequency was found on oscillograph records taken when the fin was given a sharp blow. The tab frequency was about 20 cycles per second, so that a coupling between the tab vibration and the upper-fin and leaf-spring vibration is evident.

CONCLUDING REMARKS

In the tests on the B-34 fin-rudder-tab assembly in the NACA 8-foot high-speed tunnel, flutter occurred with the original or heavy tab at slightly over 300 miles per hour. This speed is lower than the speeds obtained for cases observed in flight, because of unavoidable differences between wind-tunnel and flight conditions. The flutter resulted simply from the fact that the tab frequency was low enough to couple with one of the lower rudder-fin bending modes. It is noted that these lower modes will cause a strong coupling since there are few nodal lines, whereas the higher modes may have one or more nodal lines passing through the tab. In the two cases studied in the wind tunnel, a low bending of the fin-rudder combination was involved. In a flight test reported by Unholtz in 1943, it appeared that the rudder torsion mode was involved. The present tests therefore indicate clearly that the tab frequency must be high in order to avoid the strong coupling with the lower modes. Because of the cut-out in the B-34 rudder, there were three distinct lower modes rather close together, which in the simplest terminology were: (a) lower fin-rudder bending at 31.5 cycles per second, (b) upper fin-rudder bending at 14.3 cycles per second, and (c) rudder torsion at 44 cycles per second. Evidence shows that any one of these modes could have caused flutter. It cannot be stated categorically how much the tab frequency should be increased to prevent flutter, but it is evident that a high enough tab frequency would solve the problem.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., September 6, 1944

TABLE I. - RESULTS OF VIBRATION TESTS

Configuration	Vibration frequency, cps					
	Tab		Rudder torsion	Fin		Fuselage side bending
	Rudder blocked	Rudder not blocked		Upper	Lower	
B-34 tail on steel brackets attached to concrete block; rudder trim-tab control unit installed	32.5		41	11.3	31.5	
B-34 tail on leaf springs in NACA 8-foot high-speed tunnel; rudder trim-tab control unit installed		30.0	44	14.3		7
PV-1 tail on leaf springs in NACA 8-foot high-speed tunnel; $\frac{3}{32}$ in. by 1 in. cold-rolled steel spring	20	18.0	41			7

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TABLE II.- RESULTS OF TESTS OF MILD FLUTTER

[Phases with rudder trim-tab control unit installed; tab play, 0.6°; velocity, 308 mph; Mach number, 0.400; flutter frequency, 33.6 cps. One record was subjected to a Fourier analysis to determine fundamental of tab position indicator.]

Position	Phase (deg)
Rudder position indicator	137
Tab position indicator	0
Upper-rudder paddle	130
Lower-rudder paddle	123
Upper-rudder trailing edge	130

TABLE III.- RESULTS OF TESTS OF SEVERE FLUTTER

[Tab play, 0.4°; flutter frequency, 18.3 cps; velocity, 321 mph; Mach number, 0.411]

Position	Phase (deg)
Rudder position indicator	86 to 125
Tab position indicator	0
Fin	39
Lower-rudder trailing edge	42
Upper-rudder paddle	20
Lower-rudder paddle	-149
Upper-rudder trailing edge	47

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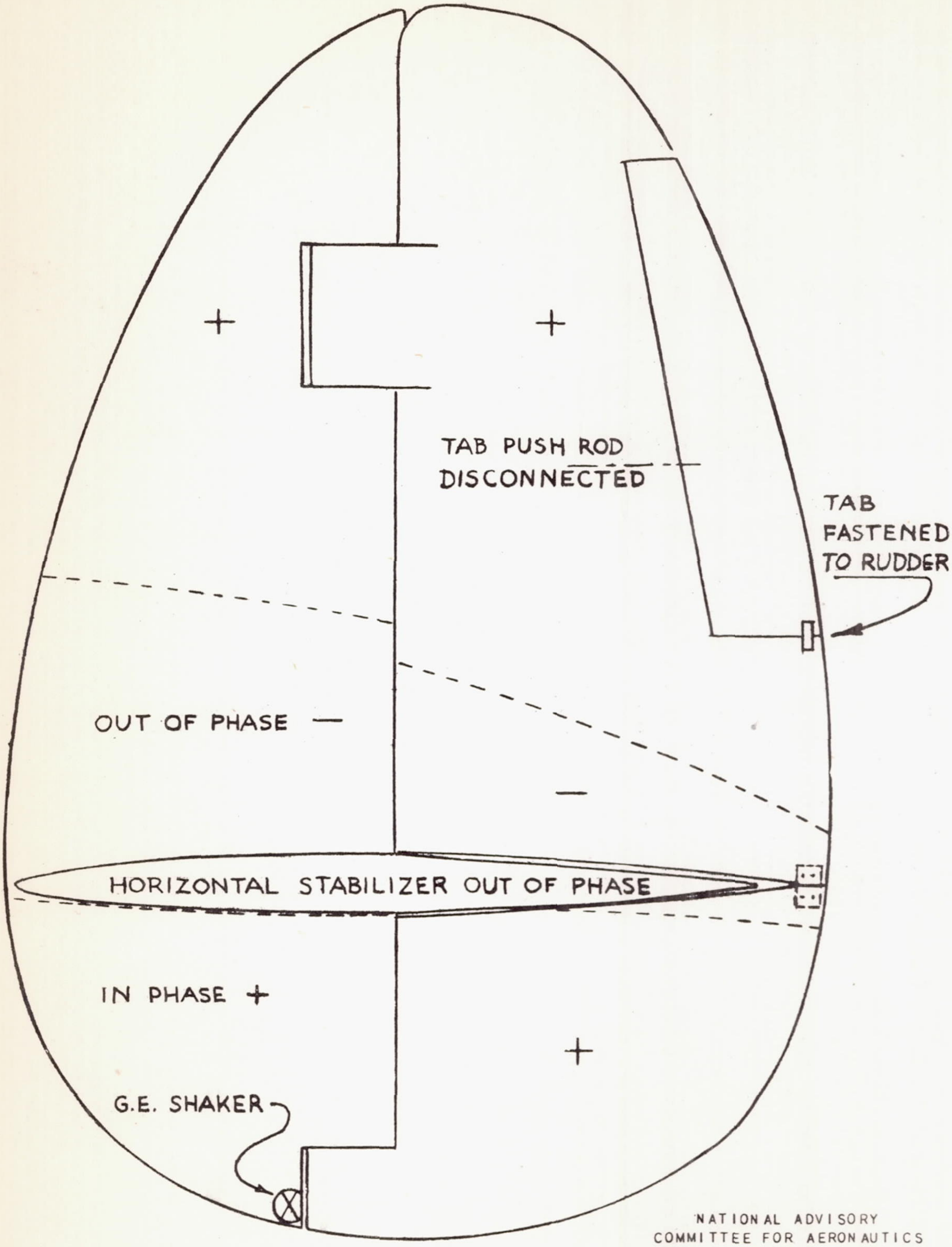

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Figure 1.- Mode of vibration at 31.5 cps.

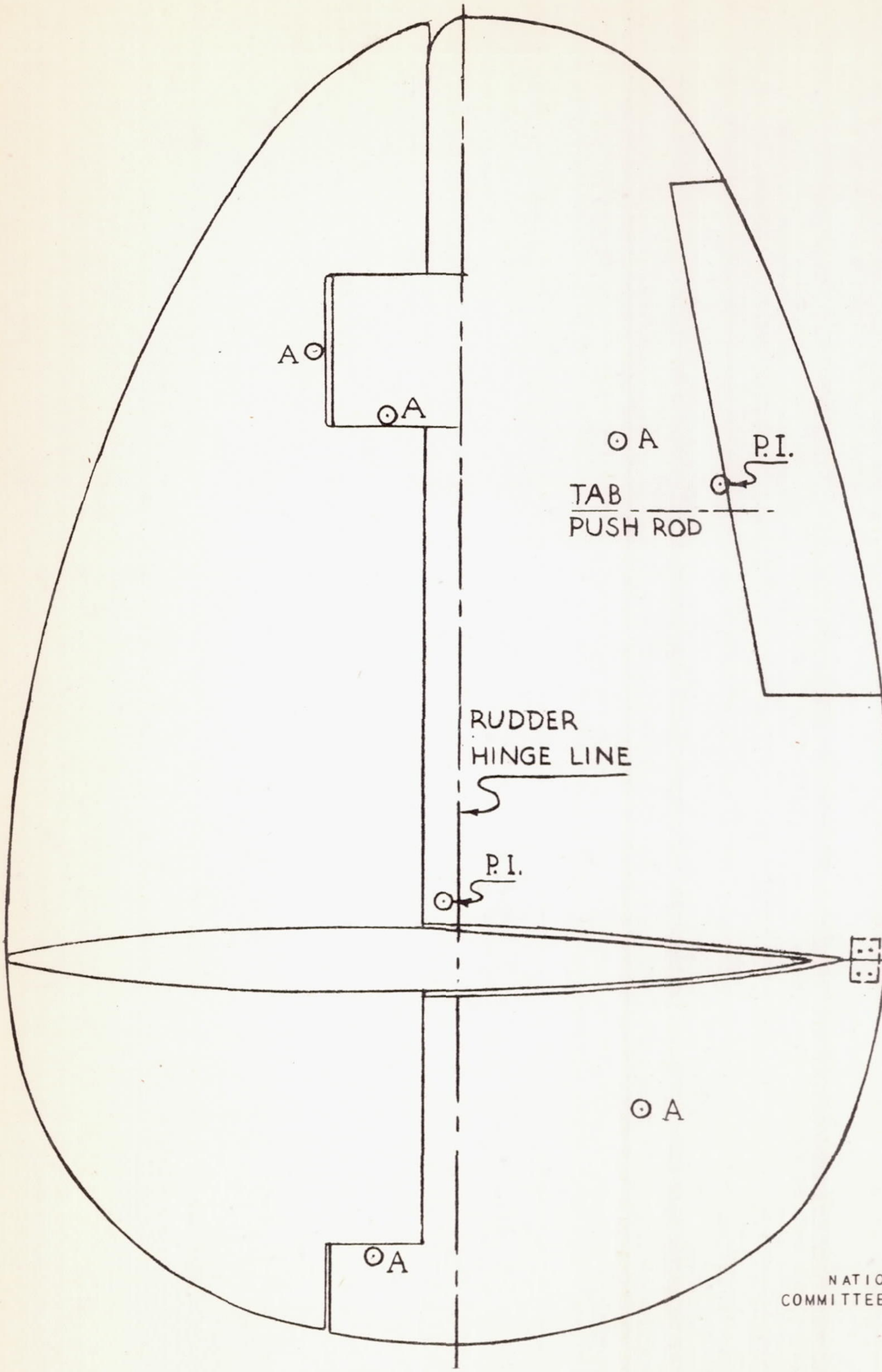

Figure 2.- Location of accelerometers and position indicators.

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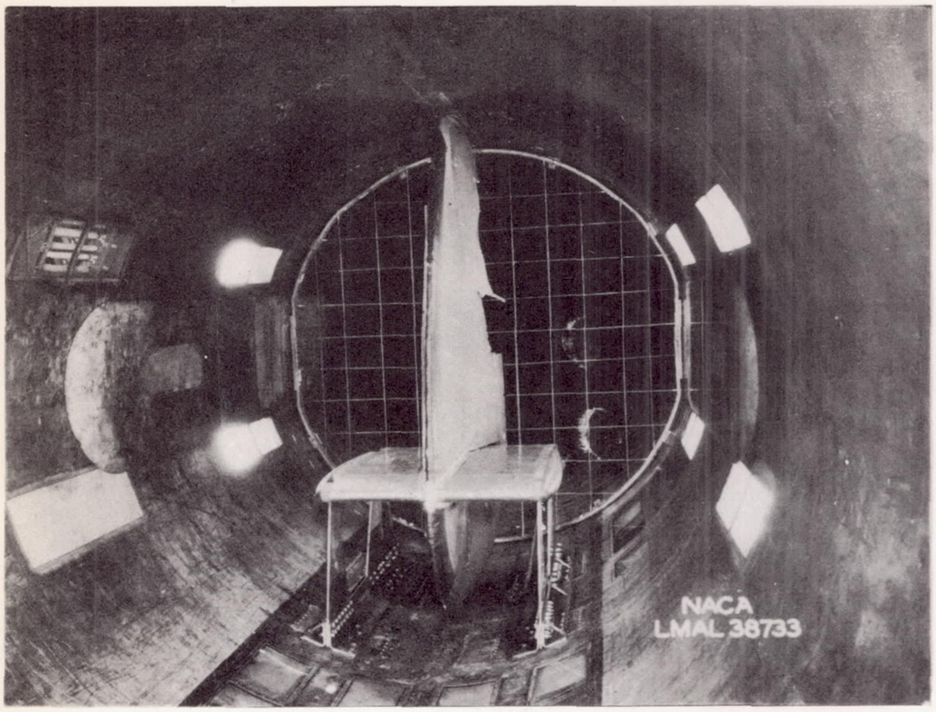

Figure 3.- Tail surface used in the tests, shown mounted on four vertical steel leaf springs in NACA 8-foot high-speed tunnel.

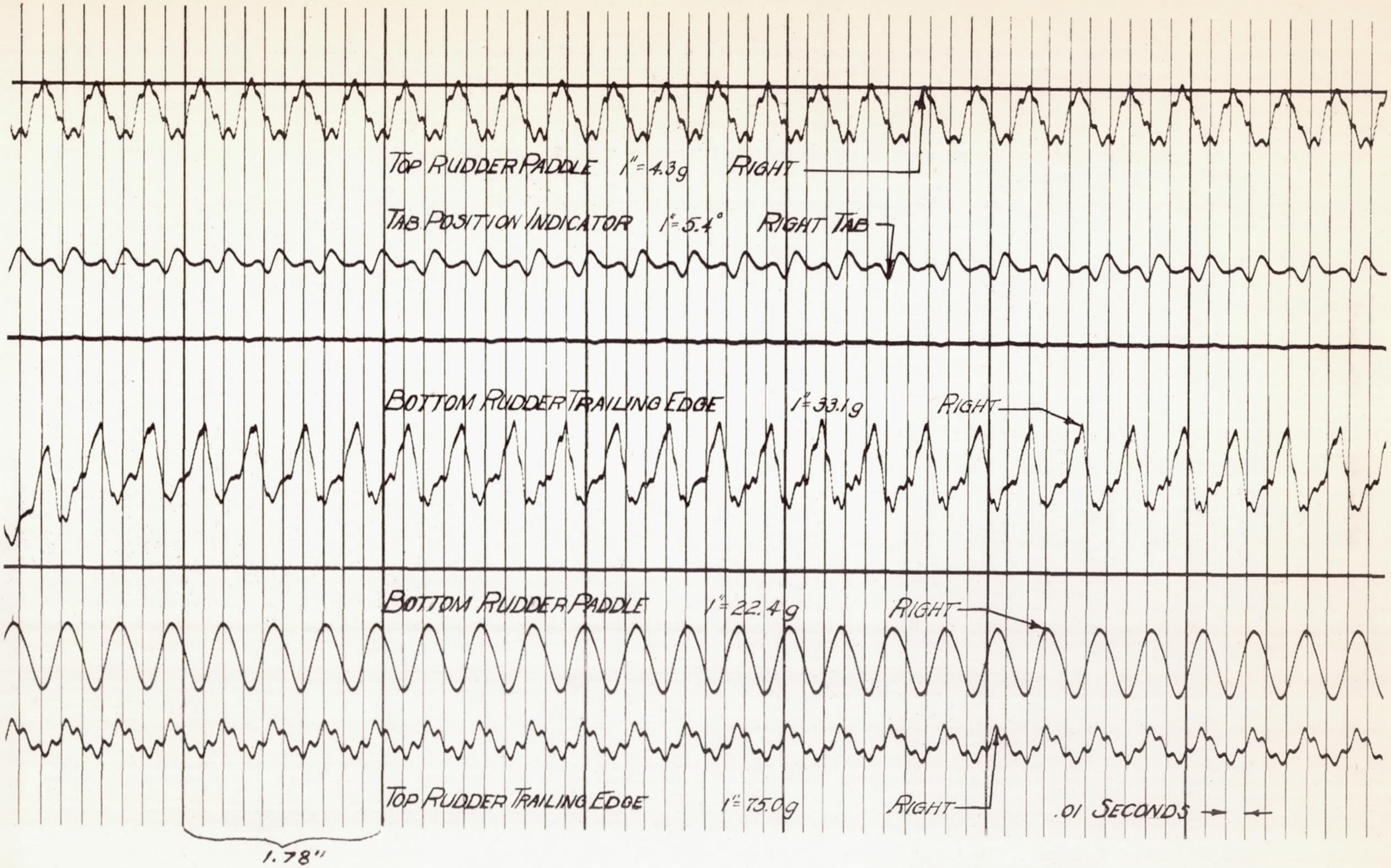

Figure 4.- Oscillograph record with rudder-torsion shaker on lower-rudder trailing edge.

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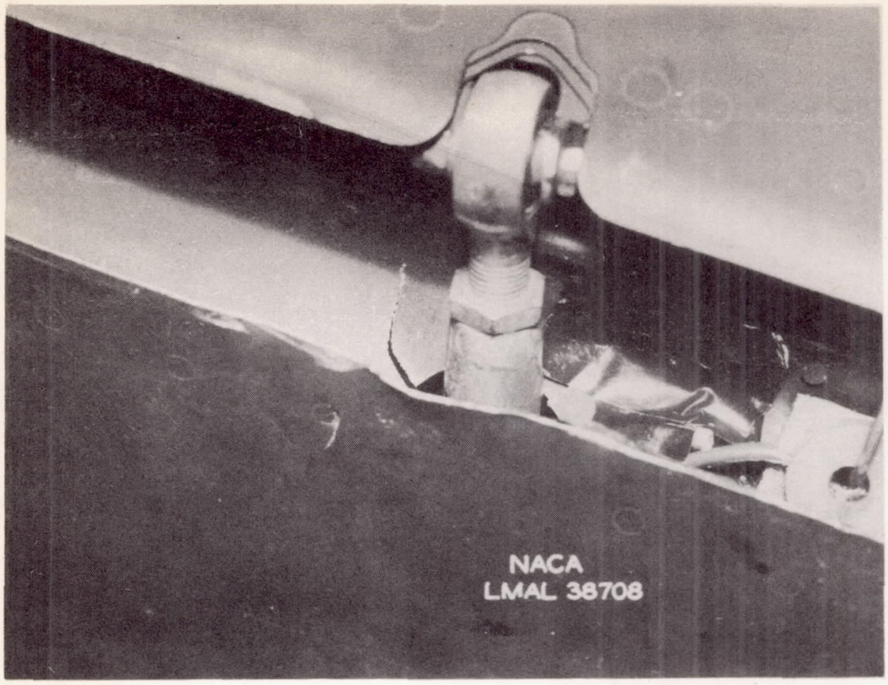
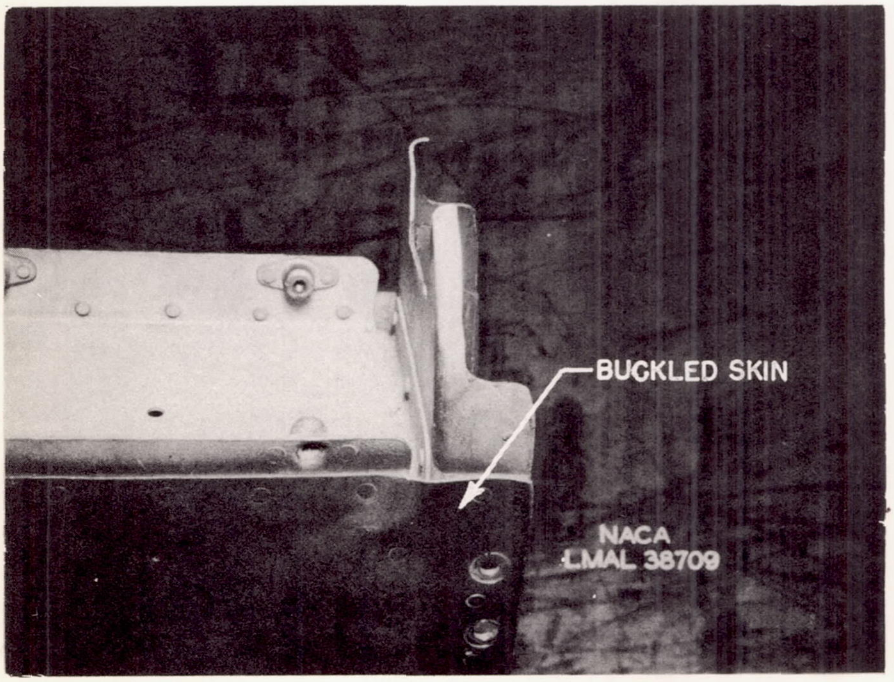


(a) Damage to trailing edge of rudder.



(b) Buckled skin on upper part of rudder.

Figure 5.- Damage to rudder caused by flutter which occurred during rapid increase in speed of tunnel.

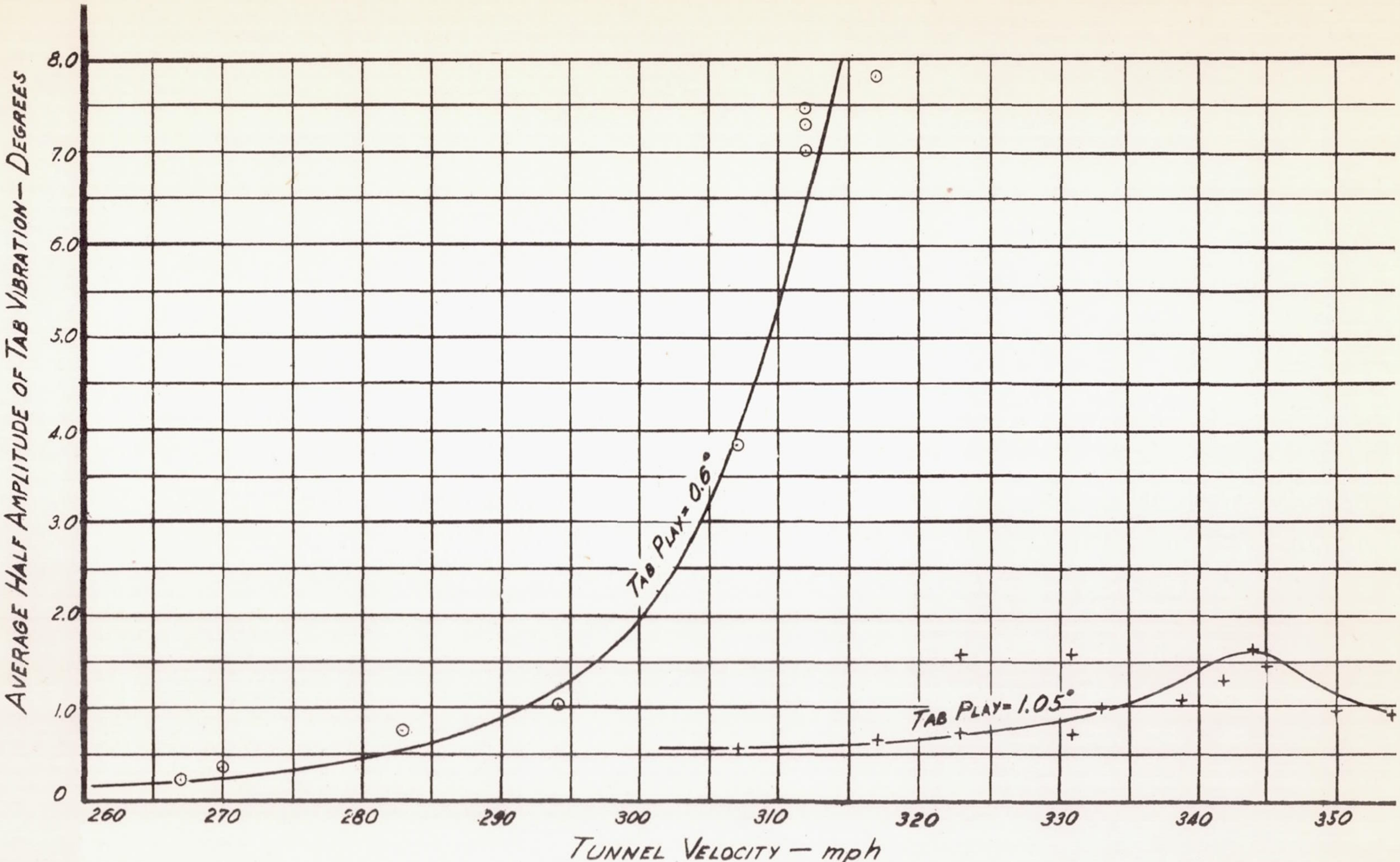


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Figure 6.- Amplitude of tab motion as a function of tunnel velocity.

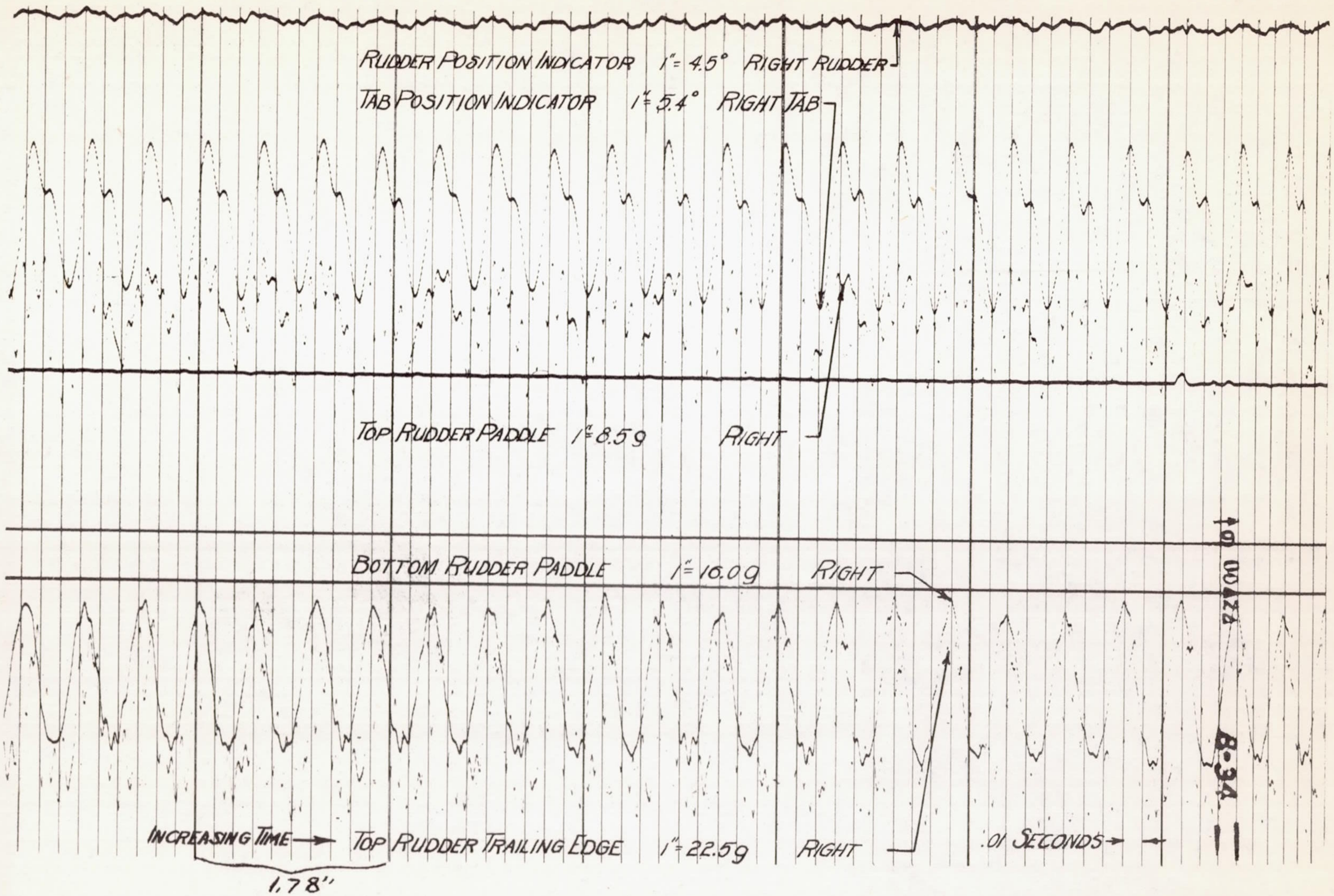

Figure 7.- Typical oscillograph record showing mild flutter. Tab play, 0.6°; velocity, 308 mph; Mach number, 0.392; tab frequency, 32.5 cps.

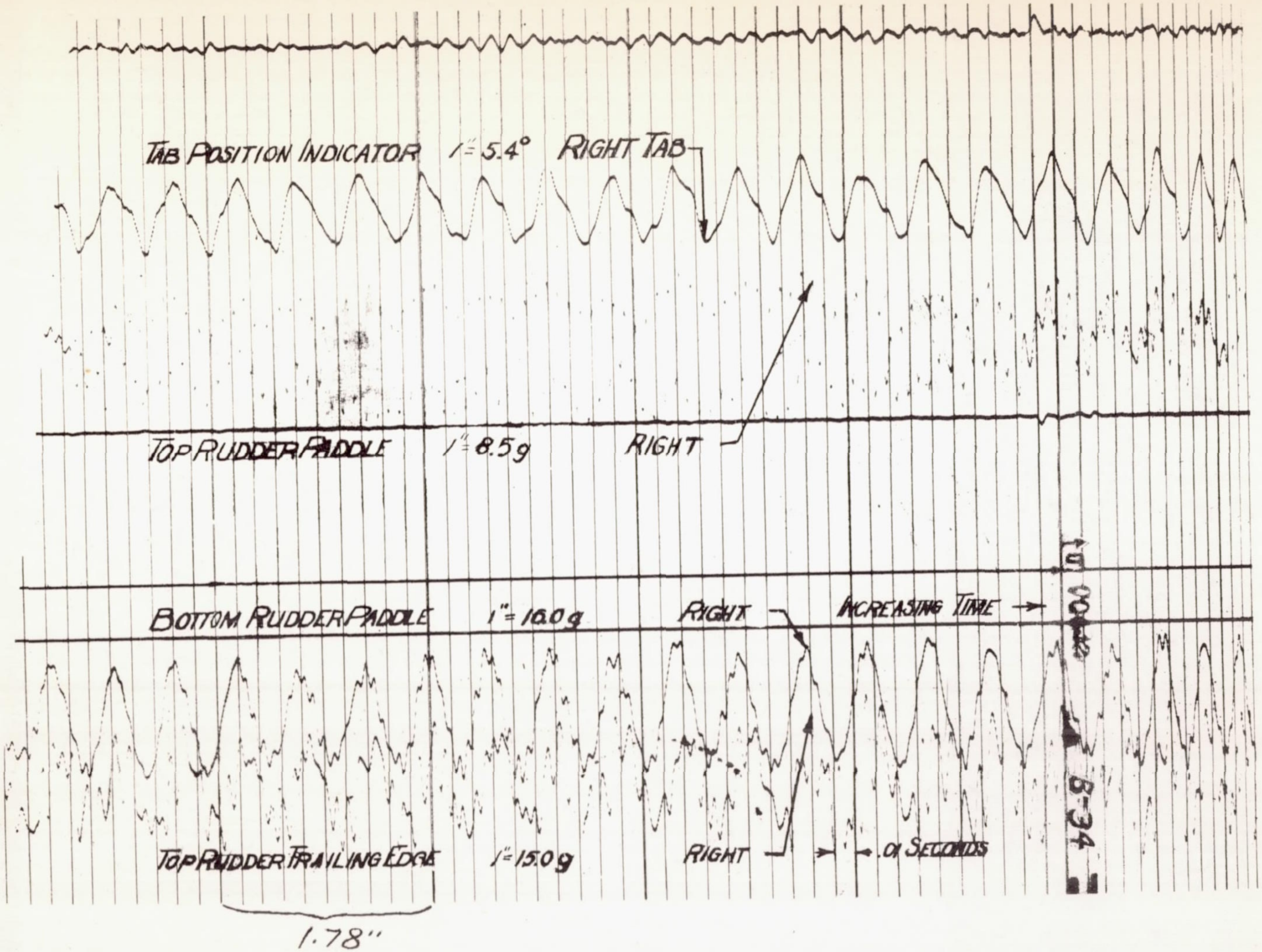

Figure 8.- Typical oscillograph record showing mild flutter. Tab play, 1.05°; V = 344 mph; M = 0.440; tab frequency, 32.5 cps.

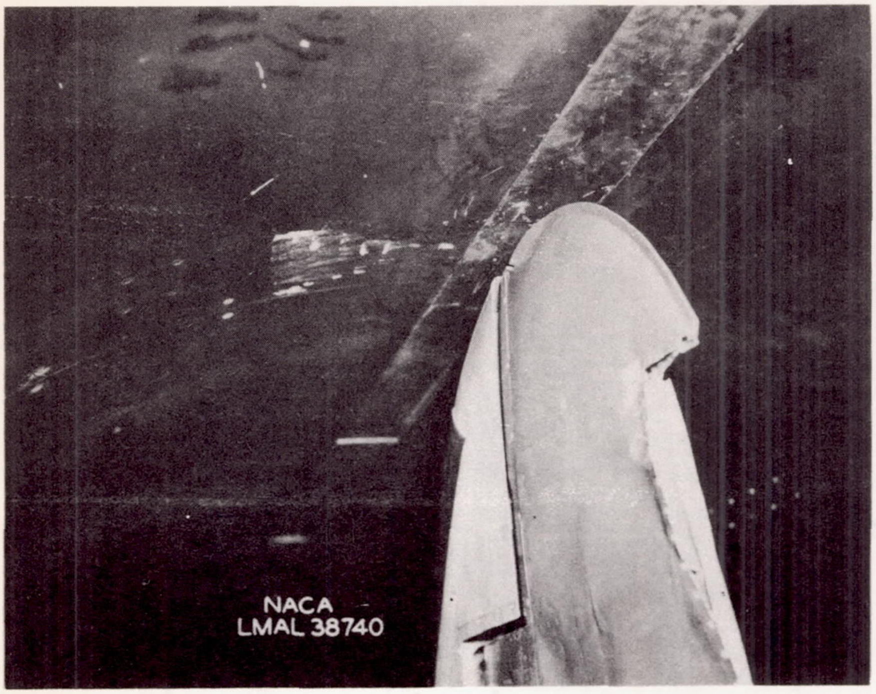

Figure 9.- Large horizontal displacement of fin during severe flutter indicated by marks on top of tunnel.

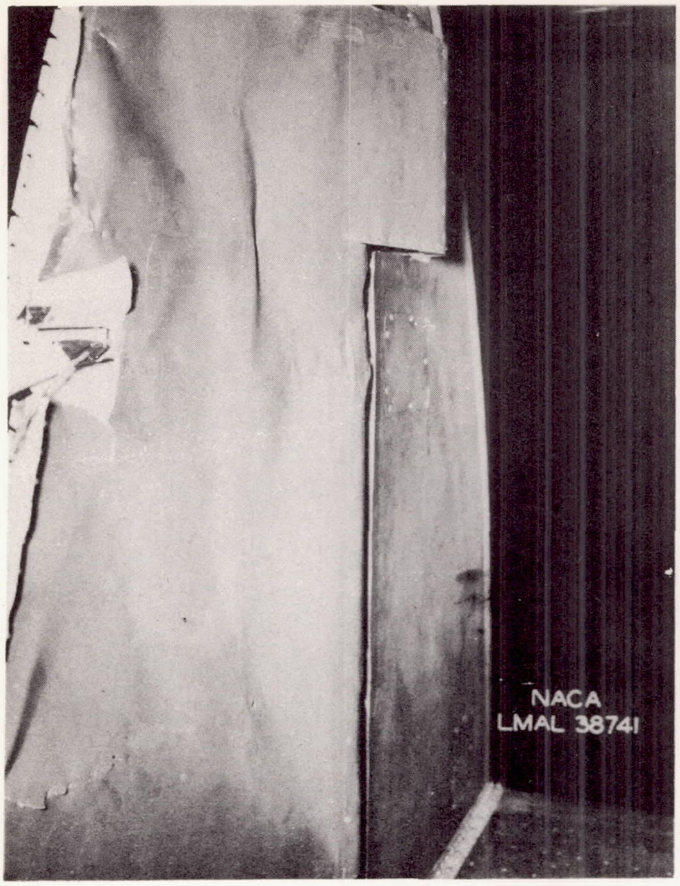

Figure 10.- Damage to tail surface caused by severe flutter.

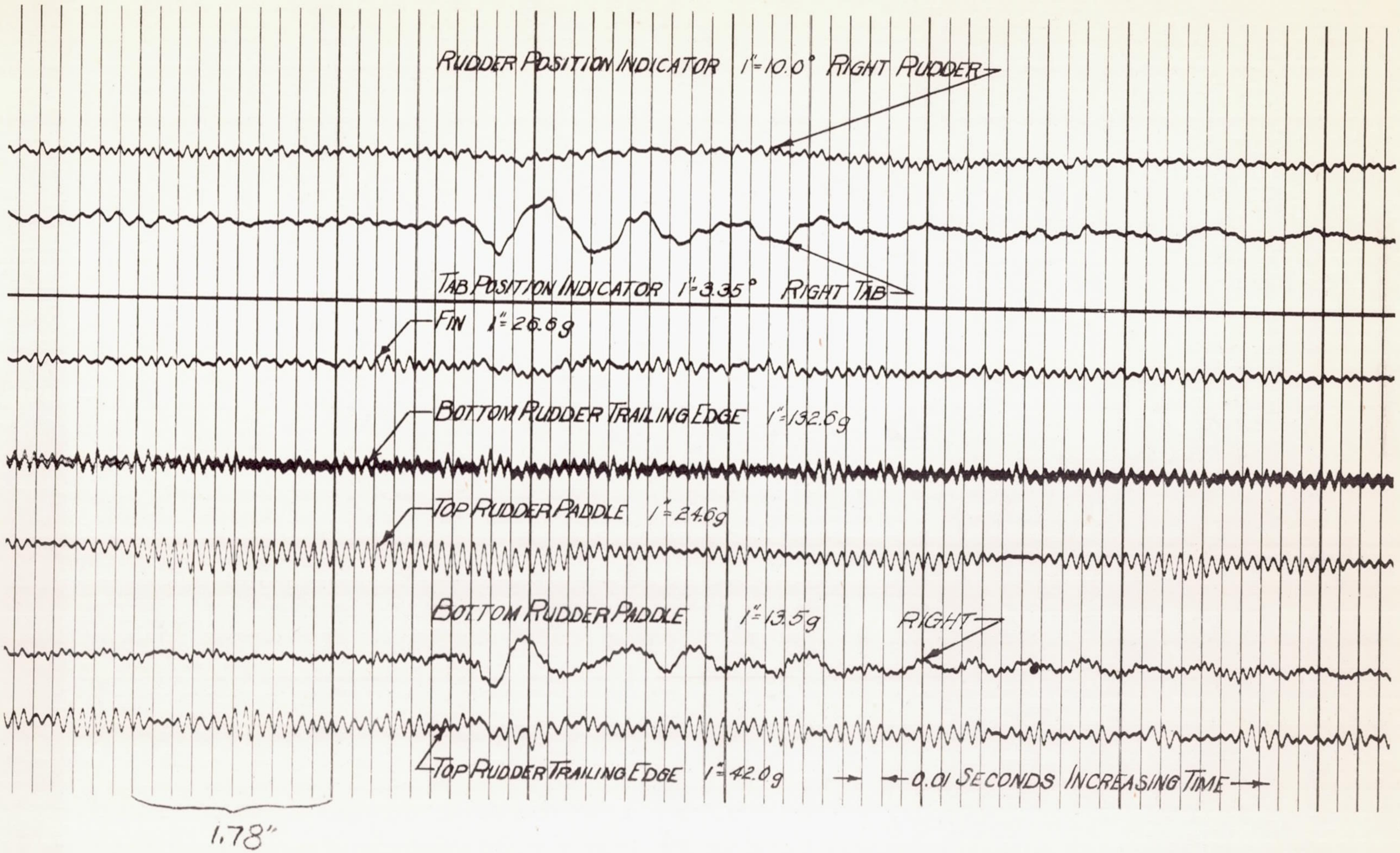

Figure 11.- Oscillograph record taken when rudder was jerked. Tab play, 0.4°; V = 311 mph; M = 0.398; tab frequency, 20 cps.

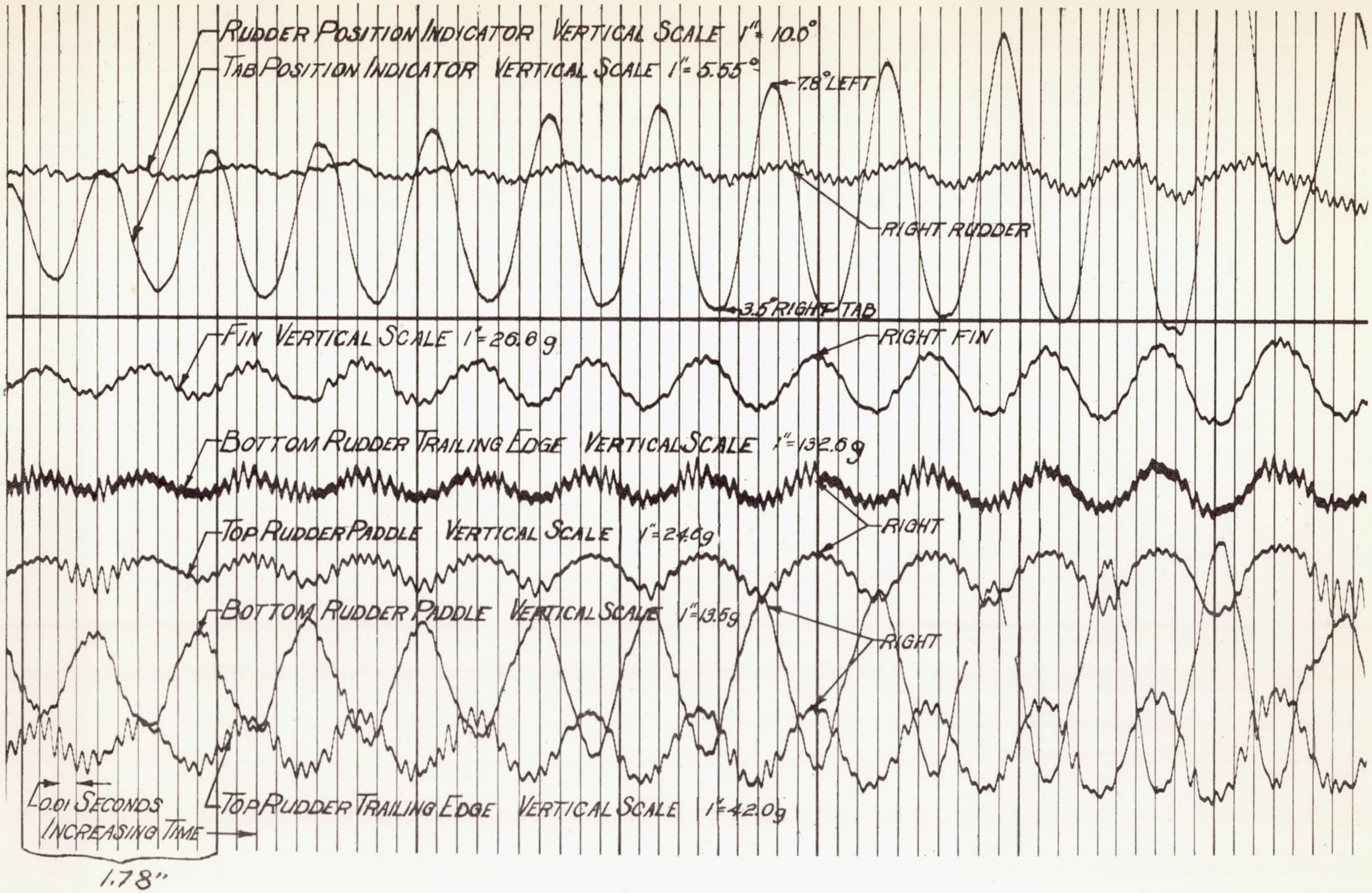

Figure 12.- Oscillograph record for case of severe flutter. Tab play, 0.4°; V = 321 mph; M = 0.411; tab frequency, 20 cps.

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